UPGRADED BRASSBOARD PULSER FOR HELS

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Summary

High energy lasers for Army tactical weapons systems requires major advances in pulse power technology to meet the objective of mounting the weapon system on a mobile platform. The power conditioning pulser is one of the largest sub-systems. The Electronic Technology and Devices Laboratory (ET&DL), ERADCOM is actively involved in developing components and pulser sub-systems to meet that objective. The unique power facility at ET&DL has been utilized on a cooperative basis with industry to develop the hardware which has had a significant impact in the size and weight of demonstrator devices. A brassboard pulser designed and built at ET&DL for the Cold Flow Electric Laser Device (CFELD) at Avco-Everett weighed 1400 kilograms (kg) representing an almost A 10X reduction from the 13,000 kg pulser that utilized available production technology.[1] The length of the pulser was similarly reduced from 48 meters to 4 meters. The brassboard consisted of multiple modulators operating in parallel with a single output transformer.

The use of this device in support of high energy laser technology has led to the construction of several iterations of like design which are capable of independent operation or parallel operation with each other and/or the brassboard pulser. The purpose of this paper is to review briefly the design concept of the one megawatt (MW) average power module which is the basic building block of the pulser subsystem. Subsequently the design of three 2 MW average power add-on pulsers will be discussed and results of rep-rate testing of a representative five module pulser will be given.

One Megawatt Average Power Module

Prior component development has culminated in a one megawatt (MW) average power module shown in Figure 1. The switch is a MW average power (MAPS-40) thyratron rated for 40 kilovolts (kv) peak voltage, 40 kiloamperes (kA) peak current and 50 amperes (A) average current.[2]

Two 1 ohm (Ω) pulse forming networks (PFNs) are employed per module. When resonantly charged from a 20 kV power supply each PFN stores 4 kilojoule (kJ). Each module, can operate with the two networks in parallel or series to provide a 10 microsecond (μs) or 20 μs pulse width with a total energy of 8 kJ. PFN capacitors used to date have polycarbonate-kraft paper-castor oil dielectric and have a PFN energy density of 66 J/kg.[3] Polypropylene capacitors have been developed which provide a PFN energy density of 150 J/kg which will be integrated into future pulser modules.[4]

Each module has an end-of-line clipper circuit for load mismatch and fault protection.[5] This circuit consists of a solid-state diode stack in series with a matched load. The series combination is connected in parallel with the end capacitors of the PFNs. The diode stack has 40 Westinghouse compensated diodes, type 1N4594. These diodes are rated for 1000 volts peak inverse voltage at 150A. A matched 0.5Ω load resistor is obtained by paralleling two 1Ω resistor stacks of four 0.25Ω carborundum washer resistors.

Since there is a low ratio of on-time to off-time for weapon system applications, module components were designed for adiabatic mode operation. The components internal heat capacity maintains the temperature rise at sub-critical levels during burst operation and cool to ambient during the off-time. This allows their power handling capability to be increased by several times over steady-state operation without increasing the size and/or adding sophisticated cooling techniques. The life objective is a minimum of 10^6 shots.

A complete pulser subsystem in addition to a required number of modules would include a charging choke and pulse transformer dictated by laser rep-rate and voltage. Logic circuitry for fault analysis and activation of protective relays is covered in a separate paper.[6]

Add-On Unit

During the past two years, ET&DL has been tasked to provide pulsers for high energy laser development programs in which there was a commonality in required pulser design but a difference in operational parameters such as rep-rate, pulse width, average power and peak voltage. To minimize development time and funds by utilizing existing hardware, the concept of add-on units became highly desirable. Figure 2 shows one of the three units built to date. Each unit consists of two of the one MW modules described above. The add-on unit characteristics are listed in Table 1.

The add-on units are stackable (Figure 3) with separate cables from each unit to the charging choke (input) and pulse transformer (output). In addition, each unit will be provided with its own slice of optically isolated logic, now under development, to detect prefires, misfires and continuous conduction and activate protective circuitry.

The add-on units were designed to promote flexibility and maintainability, and, therefore, are intentionally of low component packing density. PFNs are skid mounted for ease of replacement due to wear or to meet differing pulse requirements. A 10 or 20 μs pulse width can be obtained through a simple strapping arrangement.

Rep-Rate Testing of a Five Module Pulser

Due to limitations in available power supplies at ET&DL (maximum one MW average) testing of a multi-MW line type pulser utilizing the design described, had been limited to testing individual one MW modules at full power or a number of modules at low average power. Single shot testing was performed with the brassboard using a power supply at Avco-Everett.

A five module pulser was subjected to rep-rate testing into a dummy load when a 4 MW power supply, was made available through the Air Force (J. O'Loughlin-Kirtland AFB). A five module pulser was chosen primarily on availability of the MAPS-40 thyratrons. A 250 millihenry(mH) choke was used in conjunction with the power supply to resonance charge the networks at 100 pulses per second. Network voltage could be varied from approximately

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20 to 40 kV. Output pulses were coupled to the dummy load through an 8.5:1 step-up pulse transformer (Figure 4). The liquid load was a 14 Ω copper sulfate-sulfuric acid solution. After an aging period, a 10,000 pulse test was run. The fixed parameters for the test are given in Table 2.

The power supply was adjusted so that the peak anode voltage on the thyratrons (Epy) was 34 kV. Under these conditions, the calculated energy per pulse, E_L, was:

$$E_L = (\beta V_p)^2 \cdot \tau_p/R_L$$
$$= (8.5 \times 17\ \text{kV})^2 \cdot (20\ \mu\text{s})/14\Omega$$
$$= 30\ \text{kJ}$$

where V_p is the transformer primary voltage, 17 kV. The average power was 3 MW which was dictated by the power dissipation capability of the liquid load.

The calculated energy stored in the PFNs, $C_T V^2/2$, was 29 kJ. The pulse energy measured at the load was 25 kJ. Approximately 86 percent of the stored energy was transferred. Load current and voltage waveforms are given in Figure 5.

The pulser was run for a total of 10,013 pulses in one second (100 pulse) bursts separated by 10 seconds. After three bursts the pulser was allowed a 30 minute cool-down prior to the next three bursts. During the test, four kick-outs occured. All four were the result of a thyratron's failure to recover prior to the start of a subsequent charge cycle and were associated with the second pulse in a burst. Figure 6 shows the network voltage beginning with the second pulse (the first pulse is not recorded due to the triggering method). Initially the network is charged to the power supply voltage, 17 kV, prior to receiving a trigger signal. The first pulse is at approximately one-half the resonant voltage. As a result of this, on the subsequent charge cycle, a network voltage 10-15 percent higher than the resonant voltage is obtained before resonant conditions are achieved. The second pulse overvoltage, approaching 40 kV, produced the observed kick-outs. Fault detection circuitry for each module was not available to determine if the thyratron recovery problem was localized to just one of the five used.

In addition to the kick-outs, one prefire was recorded which did not cause power supply shut down. No misfires were recorded.

Conclusions

Compact multi-MW pulsers for high energy lasers designed to operate in the adiabatic mode have demonstrated a rep-rate capability. Reliability will improve as experience is accrued at increasing average power. To that end, a new 6 MW power supply has been installed at ET&DL, (Figure 7), which will facilitate multi-module pulser sub-system evaluation at power levels previously unavailable. Flexibility in the design of the add-on units will extend the useable life of current hardware while meeting the changing system requirements in the emerging area.

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Table 1

Basic Characteristics of Add-on Unit

	Cond. A	Cond. B
Peak Voltage(kV)	40	40
Energy (kJ)	16	16
Peak Current (kA)	80	40
Peak Power (MW)	1600	800
Average Current (A)	100	100
Average Power (MW)	2	2
Pulse Width (μs)	11	22
Rise Time (μs)	1	<1
Max Pulse Rep-Rate (MHz)	125	125
Anode Delay Time (μs)	<0.2	<0.2
Anode Delay Time Drift (μs)	<0.1	<0.1
Weight	580 kg	580 kg
Volume	$7m^3$	$7m^3$

Table 2

Test Conditions for 5 Module Pulser

Pulse Width	(τ_p)	-	20 μs
Total Capacitance	(C_T)	-	50 μF
Network Impedance	(Z_N)	-	0.2Ω
Load Resistance	(R_L)	-	14 Ω
Pulse Repetition-Rate	(PRR)	-	100 PPS
Transformer Ratio	(β)	-	8.5:1

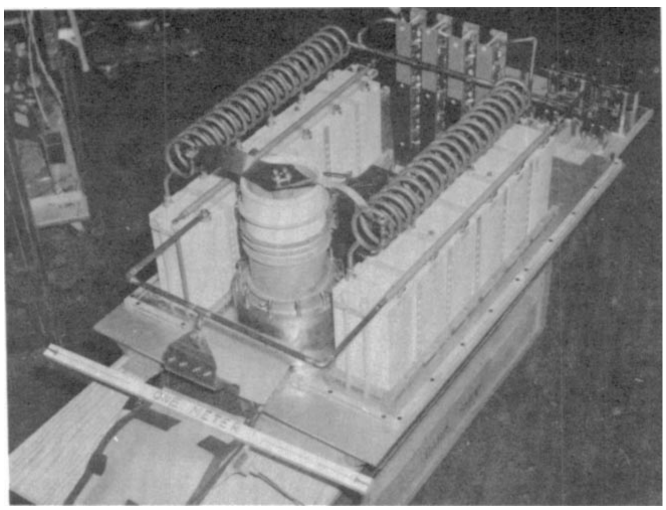

Figure 1. Compact One Megawatt Pulser Module

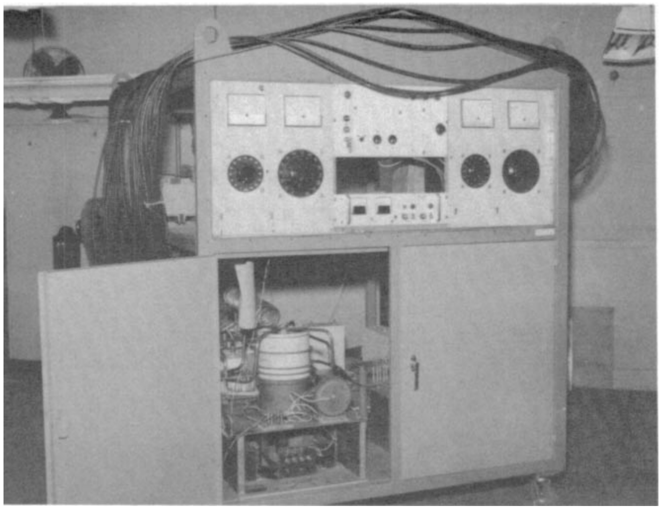

Figure 2a. Front View - Two Megawatt Add-On Unit

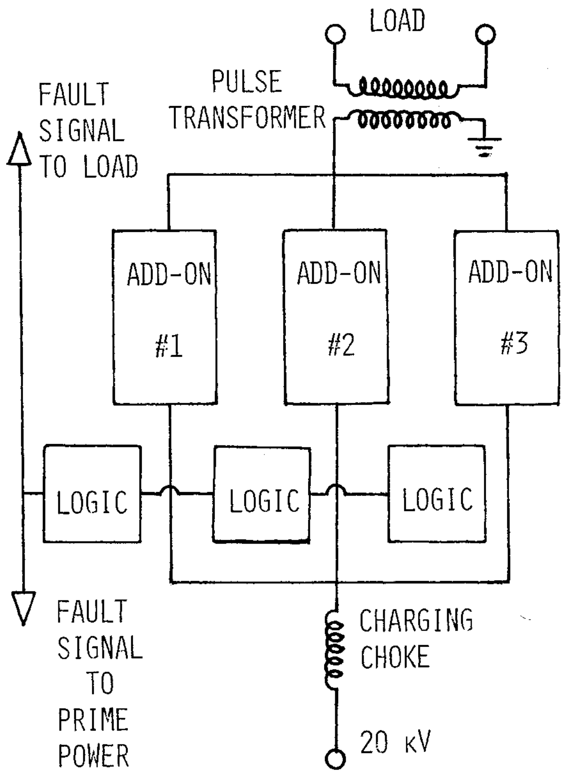

Figure 3. Circuit Diagram of Parallel Stacked Add-On Units

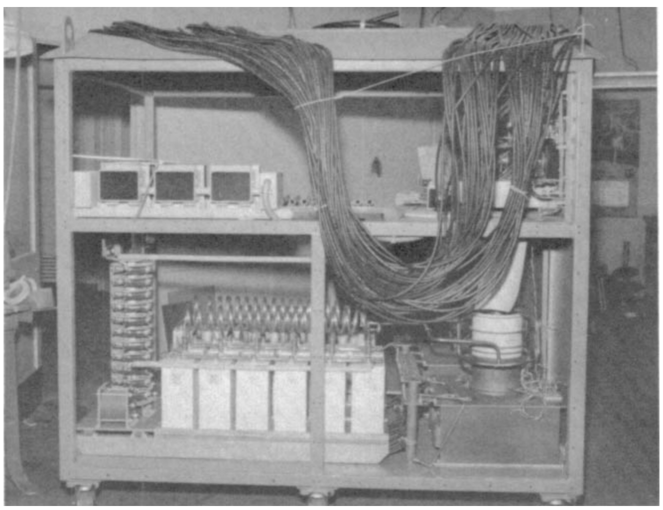

Figure 2b. Side View - Two Megawatt Add-On Unit

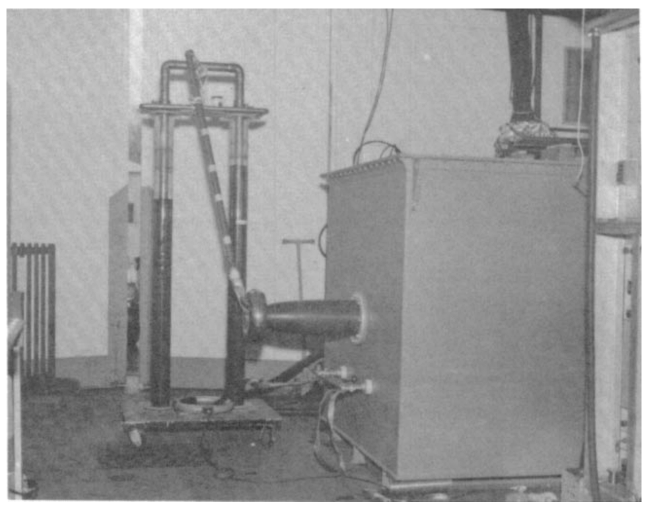

Figure 4. 8.5:1 Step-Up Pulse Transformer and Copper Sulfate Load

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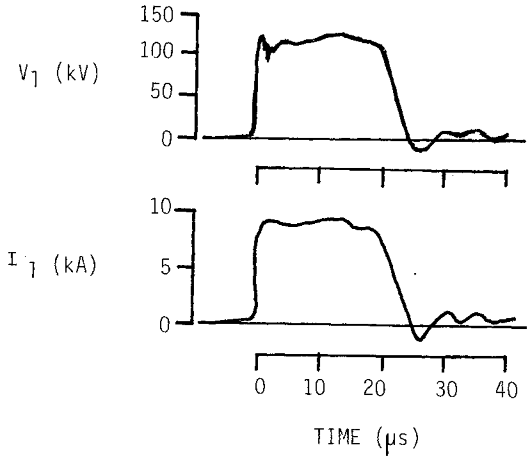

Figure 5. Current and Voltage Waveforms of Five Module Pulser

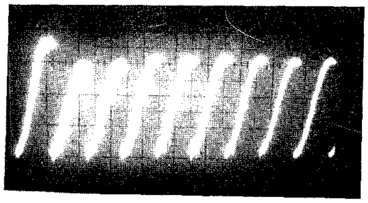

Figure 6. Network Voltage of 100 Hz Resonant Charged Five Module Pulser

Figure 7. Six Megawatt Power Supply